



# The Potential of Biochar to Enhance Environmental Sustainability in Sweden

Chibesa Pensulo

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# **THE POTENTIAL OF BIOCHAR TO ENHANCE ENVIRONMENTAL SUSTAINABILITY IN SWEDEN**

Master of Science thesis in Sustainable Development  
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Institutionen för geovetenskaper  
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# The Potential of Biochar to Enhance Environmental Sustainability in Sweden

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Pensulo, C., 2011: The Potential of Biochar to Enhance Environmental Sustainability in Sweden. *Master of Science thesis in Sustainable Development at Uppsala University*, 52 pp, 30 ECTS/hp

**Abstract:** Environmental sustainability in Sweden is challenged by rising greenhouse gas emissions from transportation, input-intensive agriculture and potentially unsustainable removal of organic material from forests and farmland. The Swedish government is working towards sixteen environmental quality objectives in order to overcome these problems, among others.

The past decade gave rise to an international research community dedicated to investigate the age-old practice of applying charcoal to soil, practiced most notably by ancient civilisations in the Amazon region of South America. The high level of interest and controversy around this subject inspired this investigation of biochar's potential benefits in Sweden.

A scientific study was conducted to examine the potential of biochar to enhance environmental sustainability in Sweden. This was largely a desk study, supplemented by expert interviews, GIS map work, an experiment and mathematical analysis.

It was found that there was insufficient research to date to prove the agronomic benefits of biochar in Sweden. More field studies are required to build up the evidence of its potential. Furthermore, as the rate of mineralization of the carbon content is dependent on numerous factors, including the composition of the soil to which the biochar is applied, it is difficult to conclusively define biochar's carbon storage potential.

This study adds to the existing body of knowledge on the subject by integrating the conclusions from a variety of studies and expert opinions, as well as by providing maps indicating land areas in Sweden that would be likely to benefit from biochar application.

**Keywords:** Biochar, bioenergy, environmental sustainability, climate compensation, soil organic matter content, agricultural productivity

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**Summary:** As part of its roadmap towards sustainable development, Sweden has identified sixteen environmental quality objectives. The key measures required to achieve these objectives are to be implemented by 2020. Various alternatives for enhancing environmental sustainability are being tested and implemented.

In the past decade, interest in the concept of biochar has surged internationally, as a potential means of capturing and storing atmospheric carbon, slowing down its re-release into the atmosphere.

This project investigates the potential for implementation of a system for producing and applying biochar in Sweden's agricultural and bioenergy sectors, and whether this would contribute to overall environmental sustainability.

Findings reveal that although there is definite potential for carbon storage, the agronomic benefits have yet to be proven conclusively. Thus, the subject is worthy of continued research, but not yet of immediate broad-scale implementation.

**Keywords:** Biochar, bioenergy, environmental sustainability, climate compensation, soil organic matter content, agricultural productivity

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# 1. Introduction

Since the Stockholm Conference on the Human Environment in 1972, Sweden has been recognized as a world leader in environmentally sustainable development, and it has become one of the world's best performing countries in environmental sustainability (Esty et al, 2006). Science and technology have played a leading role in developing new ways to protect and enhance the natural environment. Sweden has a leading position in the life sciences with regard to the quality of the science base, level of investment in research and development, and availability of skilled and experienced researchers (Rosiello, 2005). Sweden has also played a leading role in promoting environmental policy integration in Europe, having led the way by incorporating environmental concerns into policy in various sectors since the 1980s (Persson, 2004). Now, as the world faces the challenge of climate change, Sweden must again play a role in developing solutions for the future.

In 1999, the Swedish Parliament adopted fifteen environmental quality objectives, adding a sixteenth objective, on biodiversity, in 2005 (Naturvårdsverket, 2006). The sixteen objectives are listed below:

- Reduced Climate Impact
- Clean Air
- Natural Acidification Only
- A Non-Toxic Environment
- A Protective Ozone Layer
- A Safe Radiation Environment
- Zero Eutrophication
- Flourishing Lakes and Streams
- Good-Quality Groundwater
- A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
- Thriving Wetlands
- Sustainable Forests
- A Varied Agricultural Landscape
- A Magnificent Mountain Landscape
- A Good Built Environment
- A Rich Diversity of Plant and Animal Life

The conditions required to achieve these objectives are to be put in place by 2020 (Naturvårdsverket, 2006). Interventions that have multiple benefits are preferable, as all environmental factors are interlinked.

The age-old practice of applying biochar to soil has seen a resurgence of interest in recent times for its potential to offset atmospheric carbon. Biochar is the solid product of heating biomass under a limited supply of oxygen. Treating biomass in this way makes its carbon content less labile. Thus, carbon is retained in the biochar, and if applied to soil rather than consumed as fuel, constitutes a carbon storage mechanism (Lehmann & Joseph, 2009). At present, biochar is not

widely applied in Sweden for this purpose, but is recognized internationally as having potential to store carbon, as well as improve soil quality and increase agricultural yields.

This study will investigate the means of enhancing environmental sustainability in Sweden through the application of the biochar concept. In particular, the means of optimizing biochar and bioenergy production from sustainably obtained biomass in Sweden, while boosting agricultural yields without increasing commercial fertilizer input, will be identified. In order to maintain soil quality and agricultural productivity, some organic material must remain in the soil in its natural state. Thus, an important component of the project is to estimate the quantity of biomass that can be harvested for biochar production and reapplied to the soil in order to yield the desired soil quality and carbon storage.

The study identifies the land areas in Sweden that could benefit the most from application of biochar. These would be agricultural areas with meager soils that are no longer productive, have poor water retention capacity, or are clayey and could thus benefit from an improvement in particle size distribution (Maraseni, 2010). An important benefit of biochar addition to soil is that it aids retention of nutrients, thereby maintaining soil quality and preventing eutrophication of water bodies (Shackley & Sohi, 2010).

## 1.1 Problem statement

In Sweden there is a realization that the country's past agricultural practices have had long-term negative effects on the environment (Jordbruksverket, 2010). Swedish agriculture has been characterized by intensive use of chemical fertilizers and other external inputs, as well as a high level of use of petroleum products (Fogelfors et al, 2009). This is likely to become increasingly unsustainable in the future as petroleum become scarcer.

The country's local climate mitigation efforts largely consist of taxation measures (R. Abrahamsson, personal communication, 2011-11-16). The existing clean development mechanism arrangements entered into by Sweden establish carbon-negative projects in developing countries (B. Boström, personal communication, 2011-11-16) but allow Swedish industries to continue to emit greenhouse gases locally.

Current bioenergy production in Sweden is characterized by the removal of forest residue for combustion in district heating plants. The practice of returning a small fraction, about 15% of the ash to forest soils (G. Thelin, personal communication, 2011-04-05) does not yield much benefit, as it gives the soil a sudden nutrient overload, and then the nutrients are quickly washed away by surface water runoff. Thus, there is need to develop a system in which some organic matter is left in its original form as forest residues, some is burned conventionally for energy purposes, and some is converted into more stable carbon in the form of biochar, which is then ploughed into agricultural soils. It is important to note that not all soils benefit from such treatment. Thus, it would be valuable to identify the locations in which biochar application could lead to increased agricultural output.

The purpose of this study is to demonstrate how implementing biochar systems could enhance environmental sustainability in Sweden, by contributing to the attainment of Sweden's environmental quality objectives.

## 1.2 Research questions and hypotheses

This study seeks to answer the following research questions:

1. How can the implementation of biochar systems contribute to environmental sustainability in Sweden?
2. What are the most practical means of implementing biochar systems in Sweden?
3. Which areas in Sweden would benefit the most from implementing biochar systems?

The study identifies the most widely available sources of sustainably-harvestable feedstock for biomass pyrolysis, excluding the option of land use change for cultivation of feedstock except in the case of weathered and meager soils, where growing a specific high yielding crop and then turning it to biochar for the soil would restore the soil quality. An estimate of the quantity of biochar that needs to be returned to the soil in order to sustain soil quality and agricultural yields is also calculated.

In addition, means of using the energy generated during pyrolysis in order to further increase the sustainability of the process are proposed. Finally, the possibility of the state or municipalities introducing incentives for biochar production and application by farmers is discussed.

The study is based on the following hypotheses:

*Hypothesis 1: Biochar has the potential to contribute to climate change mitigation in Sweden.*

*Hypothesis 2: Biochar systems have the potential to increase agricultural productivity in Sweden, by enabling carbon-depleted soils to retain more water and nutrients, thereby reducing the amounts of agricultural inputs required.*

## 1.3 Method

It is envisioned that by triangulation of information obtained through the following methods, the study objectives will be achieved:

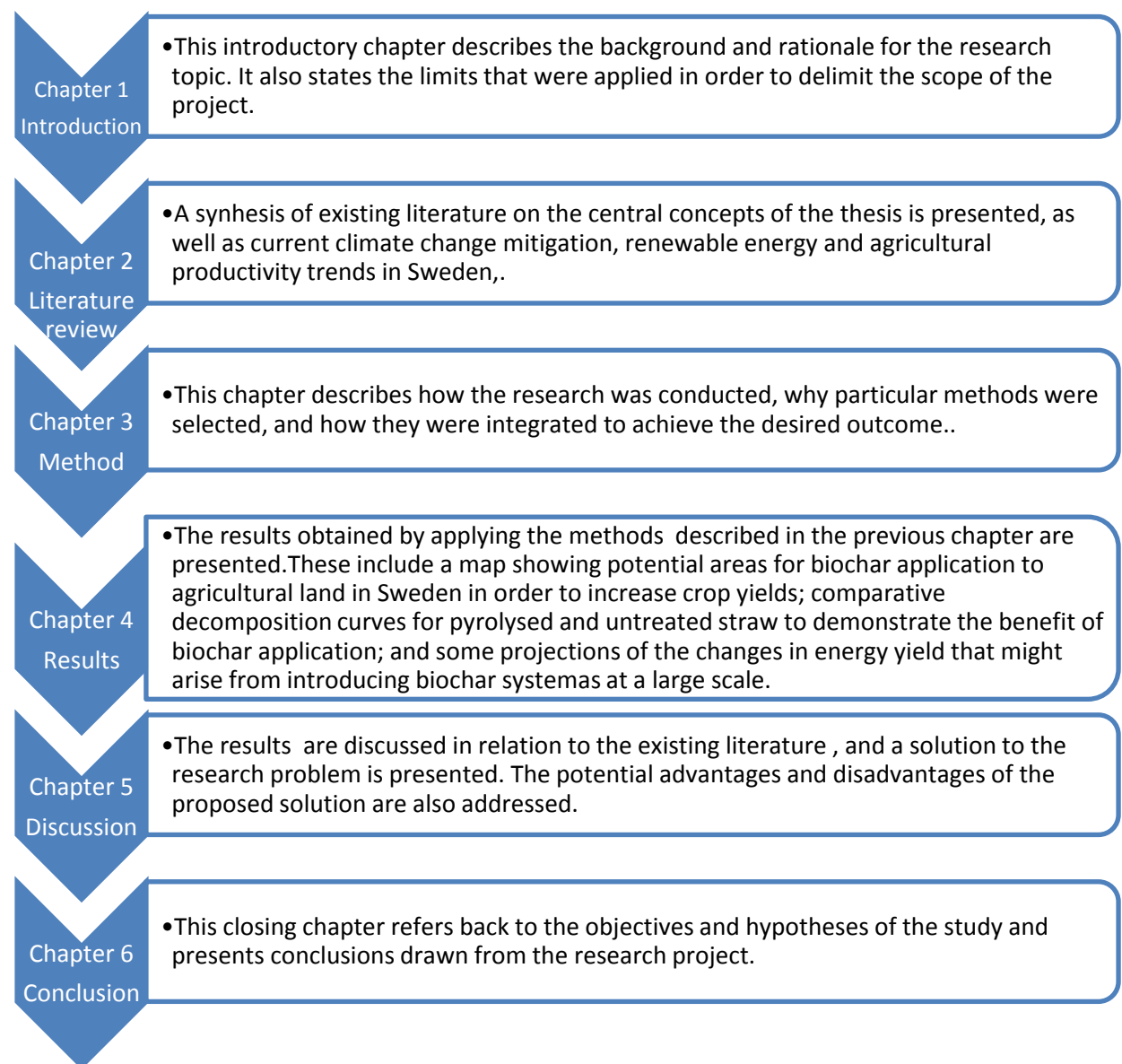
- Review of existing literature;
- Expert interviews;
- Pyrolysis experiment with agricultural residue;
- Mathematical comparison of decomposition rates of biochar versus untreated residue;
- Creation of maps indicating areas that could benefit from biochar application to soil.

## 1.4 Delimitations of the study

Biochar has numerous possible applications, but this study focuses only on those that have the potential to make a large-scale contribution to the achievement of Sweden's environmental quality objectives, namely, climate change mitigation, prevention of eutrophication and recovery of depleted agricultural soils. Thus, the study focuses on the application of biochar systems in the agricultural and bioenergy sectors.

As this was a study for a degree project with a limited time frame, there was insufficient time to conduct an exhaustive study of this subject. Additional studies would be required to further explore the viability of large-scale biochar system implementation in Sweden.

## 1.5 Disposition of the study



## 2. Literature Review

As this study is centered on investigating the potential of biochar as a means for enhancing environmental sustainability in Sweden, this chapter begins by presenting a synthesis of existing literature on environmental sustainability in general and in the case of Sweden. The current status of the sectors to which biochar is most relevant, namely agriculture and renewable energy, are also presented. Some background on the current status of climate change mitigation efforts in Sweden is given. Finally, the biochar concept is explained in further detail.

### 2.1 Environmental sustainability

Determining the degree of sustainability of any system is based on analysis on the system with respect to selected sustainability criteria. It is generally accepted that for any system to be considered sustainable, it must satisfy related environmental, social and economic considerations.

Environmental sustainability focuses on maintaining ecosystem functions that human life is dependent on. Humans are reliant on other species for food, shelter, clean air, plant pollination, waste assimilation, and other environmental services. The atmosphere, biosphere, hydrosphere and lithosphere constitute these life-support systems. All of these need to be healthy in order to maintain their ecosystem service capacity (Atkins et al, 1998). It is recognized that humanity must learn to live within the constraints of our biophysical environment. The concept of environmental sustainability originated due to social concerns, seeking to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded (Goodland, 1998).

Promoting environmental sustainability implies that natural capital must be maintained, both as a 'source' of inputs and as a 'sink' for wastes. 'Source' capacities of the global ecosystem provide raw material inputs such as air, water, energy and food; sink capacities assimilate outputs or wastes (Goodland, 1998). These source and sink capacities are large but finite. Environmental sustainability requires that they be maintained or enhanced rather than depleted. Over-exploitation of a capacity places ecosystems at risk. Thus, the scale of economic development must be kept within the biophysical limits of the ecosystems on which it is dependent. Sustainable consumption is therefore the cornerstone of environmental sustainability. On the 'source' side, harvest rates of renewable resources must be kept within their regeneration rates, and harvest of non-renewable resources must be kept to a minimum. On the 'sink' side, waste emissions must be limited to within the assimilative capacity of the environment.

According to Goodland (1998), achievement of environmental sustainability is governed by two rules:

1. Output Rule: Waste emissions from any project or action should be kept within the assimilative capacity of the local environment without irreparable degradation of its future waste absorptive capacity or other important services.
2. Input Rule: (a) Renewables: harvest rates of renewable resources should be within the regenerative capacity of the natural systems that provide them.

(b) Non-renewables: depletion rates of nonrenewable resource should be below the rate at which renewable substitutes are developed by human invention and investment.

The steps each country should take towards environmental sustainability are not the same. Although all countries need to follow the input and output rules, countries differ in the balance between output and input that will be needed to achieve environmental sustainability. For example, some countries or regions should focus on controlling pollution; other countries should rather pay more attention to bringing harvest rates of their renewable resources down to regeneration rates; some countries should limit their population growth to below carrying capacity; others, including most industrialised countries, should reduce their per capita consumption (Goodland, 1998). Sweden is in the last category.

The United Nations Millennium Summit in 2000 established the Millennium Development Goals. The seventh goal was on ensuring environmental sustainability, and had, amongst others, the following targets (UNDP, 2011):

Target 7a: Integrate the principles of sustainable development into country policies and programmes; reverse loss of environmental resources

Target 7b: Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss.

The indicators for these two targets were:

- Proportion of land area covered by forest
- CO<sub>2</sub> emissions
- Consumption of ozone-depleting substances
- Proportion of fish stocks within safe biological limits
- Proportion of total water resources used
- Proportion of terrestrial and marine areas protected
- Proportion of species threatened with extinction

There are clear parallels between these indicators and the goals Sweden set for itself, discussed in the next sub-chapter.

## 2.2 Sweden's 16 environmental quality objectives

In 2002 the Swedish Cabinet issued a national strategy for sustainable development. The strategy includes objectives and activities for all three dimensions of sustainable development (Persson, 2004; Regeringskansliet, 2004). According to this national strategy, the overall goal of Swedish environmental policy is to hand over to the next generation a society in which the major environmental problems in Sweden have been solved (Regeringskansliet, 2004), without increasing environmental and health problems outside Sweden's borders. In practice, this generational goal means that the basic conditions for solving the environmental problems Sweden faces are to be achieved within one generation, and that environmental policy should be directed towards ensuring that:

- Ecosystems have recovered, or are on the way to recovery, and their long-term capacity to generate ecosystem services is assured;
- Biodiversity and the natural and cultural environment are conserved, promoted and used sustainably;
- Human health is subject to a minimum of adverse impacts from factors in the environment, at the same time as the positive impact of the environment on human health is promoted.
- Materials cycles are resource-efficient and as far as possible free from dangerous substances.
- Natural resources are managed sustainably;
- The share of renewable energy increases and use of energy is efficient, with minimal impact on the environment;
- Patterns of consumption of goods and services cause the least possible problems for the environment and human health (Swedish Environmental Objectives Council, 2009).

To achieve this generational goal, the following environmental quality objectives have been outlined (Environmental Objectives Secretariat, 2011):

*Reduced Climate Impact:* By 2050, the ambition is that Sweden will have no net emissions of greenhouse gases into the atmosphere. Interim goals exist for 2020;

*Clean Air:* air must be clean enough not to represent a risk to human health or to animals, plants or cultural assets;

*Natural Acidification Only:* the acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water;

*A Non-Toxic Environment:* the environment must be free from man-made or extracted compounds and metals that threaten human health or biological diversity;

*A Protective Ozone Layer:* the ozone layer must be replenished so as to provide long-term protection against harmful UV radiation;

*A Safe Radiation Environment:* human health and biological diversity must be protected against the harmful effects of radiation in the external environment;

*Zero Eutrophication:* nutrient levels in soil and water must not adversely affect human health, biological diversity or varied use of land and water;

*Flourishing Lakes and Streams:* lakes and watercourses must be ecologically sustainable and their variety of habitats must be preserved;

*Good-Quality Groundwater:* groundwater must provide a safe and sustainable supply of drinking water and contribute to viable habitats for flora and fauna;

*A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos:* the North Sea and the Baltic Sea must have a sustainable productive capacity and biological diversity preserved;

*Thriving Wetlands:* the ecological and water-conserving function of wetlands in the landscape must be maintained and valuable wetlands preserved;

*Sustainable Forests:* the value of forests and forest land for biological production must be protected at the same time as biological diversity and cultural heritage and recreational assets are safeguarded;

*A Varied Agricultural Landscape:* the value of the farmed landscape and agricultural land for biological production and food production must be protected at the same time as biological diversity and cultural heritage assets are preserved and strengthened;

*A Magnificent Mountain Landscape:* the pristine character of the mountain environment must be largely preserved, in terms of biological diversity, recreational value, and natural and cultural assets;



*A Good Built Environment:* cities, towns and other built-up areas must provide a good, healthy living environment and contribute to a good regional and global environment;

*A Rich Diversity of Plant and Animal Life:* biological diversity must be preserved and used sustainably for the benefit of present and future generations.

## 2.3 Climate change mitigation in Sweden

As an industrialised country, Sweden is an Annex I party to the United Nations Framework Convention on Climate Change, and therefore has emission reduction targets to achieve. Sweden's commitments on emissions under the Kyoto Protocol and EU burden sharing are that emissions as an annual average for the period 2008-2012 will be no more than 104 percent of 1990 emissions. Sweden is on track to comfortably meeting the commitment (Ministry of the Environment, 2009).

In addition to these internationally agreed targets, Sweden has set its own targets within its national climate change policy (R. Abrahamsson, personal communication, 2011-11-16).

Sweden's targets for climate and energy by 2020 are:

- 40 per cent reduction in greenhouse gas emission in the non-trading sectors, i.e. sectors not included in the EU Emissions Trading Scheme, such as transport, housing, waste facilities and certain types of industry. Two-thirds of this reduction is to be achieved via local efforts within Sweden, and the remaining one-third through climate mitigation activities outside the country (R. Abrahamsson, personal communication, 2011-11-16);
- at least 50 percent renewable energy for electricity generation and heating;
- 20 percent improvement in efficiency of energy use;
- at least 10 percent renewable energy in the transport sector (Ministry of the Environment, 2010).

Although it is estimated that Sweden's forest absorb ten times as much as is emitted from land use (B. Boström, personal communication, 2011-11-16), this cannot be included in carbon accounting, as it may often be difficult to estimate greenhouse gas removals and emissions resulting from land use (UNFCCC, 2011). In addition, greenhouse gases may be unintentionally released into the atmosphere if a sink is damaged or destroyed through a forest fire or disease. Afforestation, reforestation and deforestation activities occurring since 1990 are accounted for, however (B. Boström, personal communication, 2011-11-16).

Greenhouse gas emissions in Sweden, excluding emissions and removals due to land use, land use change and forestry (LULUCF) decreased by 9 percent over the period 1990 to 2007 and are expected to continue to decline. Emissions in 2020 are estimated to be around 16 percent below 1990 levels (Ministry of the Environment, 2009).

The greatest decreases in emissions over the period occurred in the residential and service, agriculture and waste sectors. The decrease in emissions from the residential and service sector is mostly due to oil for heating having been replaced by biomass-based district heating and in recent years also by heat pumps and biomass pellet-fired boilers. Methane emissions from waste have decreased as a result of household waste no longer being landfilled and the collection of methane gas from landfills for energy recovery having increased. The most significant reasons for the

reduced emissions from agriculture are reduced numbers of cattle and lower use of both mineral fertiliser and manure (Ministry of the Environment, 2009).

These local emissions reductions have largely been achieved through taxation (R. Abrahamsson, personal communication, 2011-11-16). The introduction of energy tax and carbon tax has driven improvements in energy efficiency and changes in feedstock for energy generation (Brown, 2009; Carbon Tax Center, 2011).

However, emissions have increased in the transport sector and in some industries (Ministry for the Environment, 2009).

## 2.4 Renewable energy production in Sweden

In Sweden, the four main sources of energy supply are crude oil, nuclear energy, bioenergy and hydropower. Of these, bioenergy and hydropower are renewable. The chart below shows the total energy supply in Sweden in 2009. The different sources and the quantity of energy supplied by each are indicated.

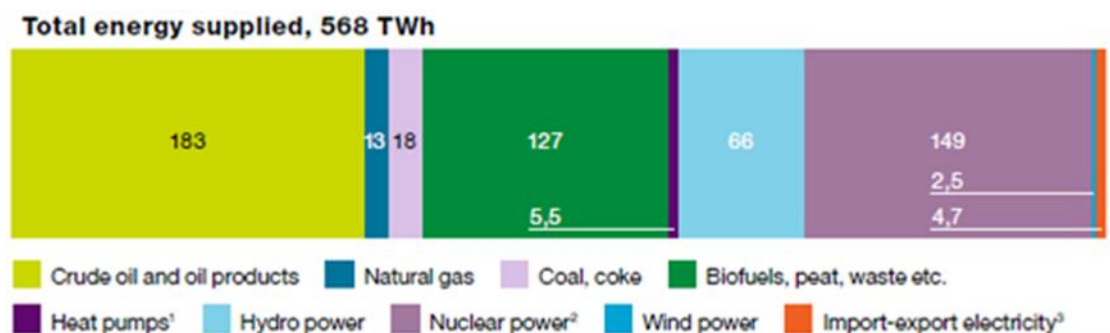


Figure 1: Energy supply in Sweden, 2009, in Terawatt-hours<sup>1</sup>

Bioenergy is of particular relevance to this study. Bioenergy is energy derived from biomass. In essence bioenergy is the utilization of solar energy that has been bound up in biomass during the process of photosynthesis. The photosynthesis process uses solar energy to combine carbon dioxide from the atmosphere with water and various nutrients from the soil to produce plant matter - biomass. Bioenergy is therefore a renewable energy resource. This definition of bioenergy excludes energy obtained from fossil fuels, because although fossil fuels have their origin in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been out of the carbon cycle for a very long time. Their combustion therefore disturbs the carbon dioxide content in the atmosphere.

Bioenergy is used in heating, fuel production, and electricity generation. Historically, almost all energy consumed the world over was bioenergy (Brown et al, 2006), but over time fossil fuels and electricity came to replace this. According to the International Energy Agency, bioenergy

<sup>1</sup>Energimyndighet, 2010 (b): Energy in Sweden – facts and figures 2010, Swedish Energy Agency, Eskilstuna, Sweden

currently supplies about 10 percent of total primary energy supply worldwide, and in 2005 accounted for 78 percent of all renewable energy. In some developing countries it accounts for up to 80 percent of total primary energy supply, whereas in most industrialized countries it provides less than five percent (IEA, 2007, cited in IUCN, 2008). However, with the need to revert to more sustainable forms of energy supply, a return to bioenergy has become of great interest in recent years. To improve the transportability and versatility of bioenergy, it is often converted to forms that resemble fossil fuels.

Renewable energy is a priority for the Swedish Government, reflected in policy and taxation that favours renewable energy production (Johansson et al, 2002). Sweden has a long tradition of using bioenergy. The country consequently has responsibility for, and can play a key role in, continued work towards increasing use of renewable energy. If used appropriately, bioenergy should make a significant contribution to climate change mitigation and to environmental sustainability development in Sweden (Energimyndighet, 2007). The country is well placed for the production of renewable energy. It has vast water resources for hydroelectric power production; there are strong winds that could generate wind power; and some of the country's abundant forest resources could be used sustainably for bioenergy (Ministry of Agriculture, 2008). Sweden has made great strides in increasing the contribution of bioenergy to the overall energy production and consumption in the country.

In Sweden the use of biomass is largely integrated with the forest industry, which, apart from its own consumption, supplies the district heating sector with low-cost wood fuels. The wood fuels include logging residues and forest industry by-products, such as wood chips, bark and sawdust. Sometimes these by-products are refined to pellets, briquettes or powder before delivery to a heating plant (Johansson et al, 2002). In addition to residues from felling of Spruce trees, short-rotation Salix forests are grown specifically for bioenergy production.

There are various reasons why only a small fraction of the total fuel straw potential is utilised in Sweden currently (Johansson et al, 2002). One reason is the weather during the harvesting period. Due to the wet autumn climate in Sweden, the number of days with suitable straw harvest conditions is relatively small. Since straw is harvested during a short period in the autumn it has to be stored until the winter when the district heating plants need the fuel. This leads to additional costs which, for example, Salix is not burdened with since Salix is harvested during the winter. The costs of harvesting, transportation and storage of straw may account for about 85% of the total straw fuel cost in district heating plants. Another factor restricting the use of fuel straw in district heating plants is the low ash melting temperature and its slagging, fouling and corrosion characteristics that would damage the equipment in the district heating plants. Such problems are much smaller with forest residues. However, in the future if the supply of cheap forest residues becomes limited in a region with abundant straw resources, the use of straw for bioenergy could increase significantly (Johansson et al, 2002). Currently, straw is used for energy purposes only in single family houses and farms (R. Abrahamsson, personal communication, 2011-11-16).

The graphs below show the trends in use of fossil fuels in Sweden in the period 1980 to 2009.

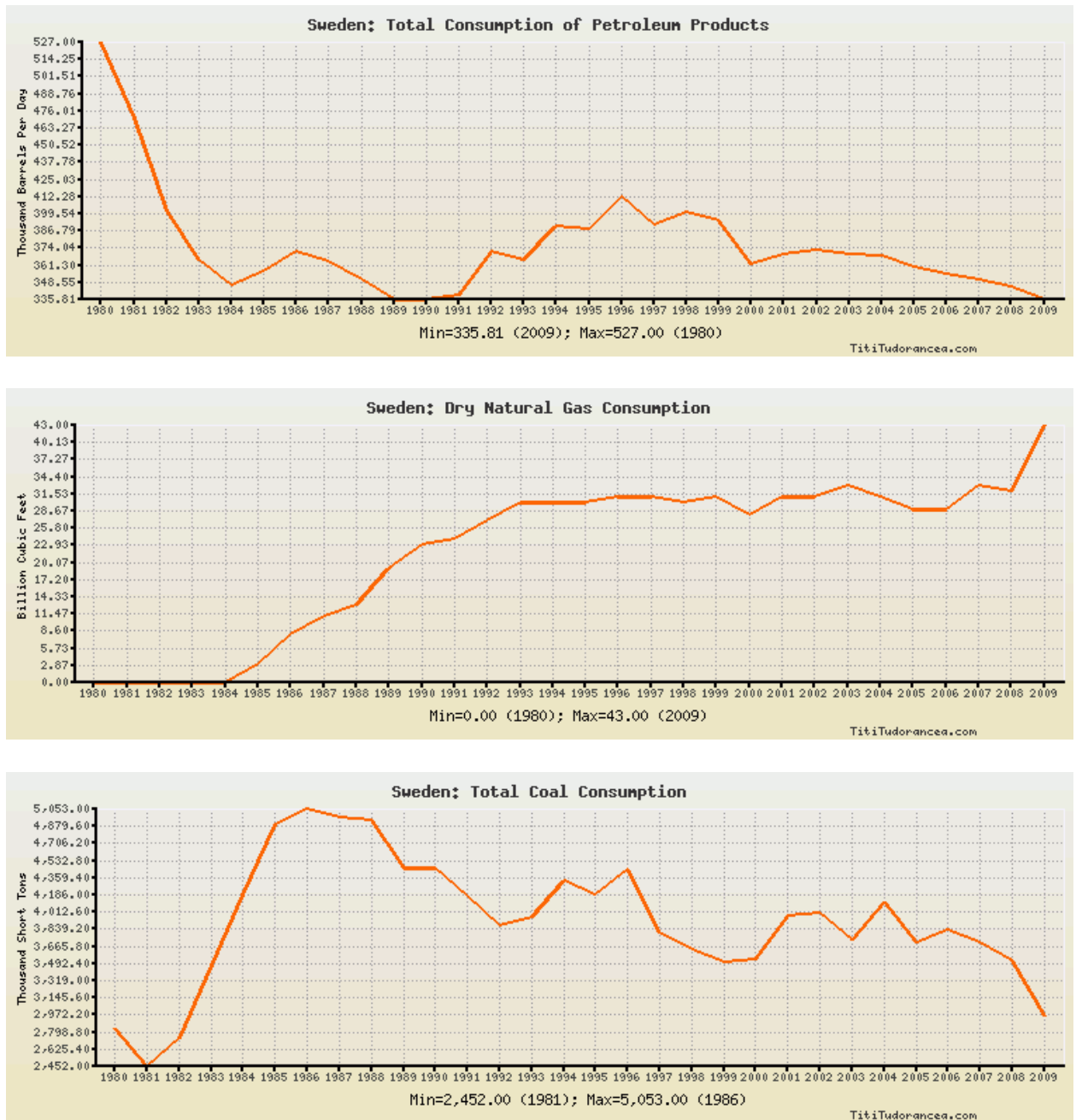


Figure 2: Fossil fuel consumption in Sweden 1980 – 2009<sup>2</sup>

The graphs show that over the past 30 years, the percentage share of petroleum and coal in Sweden's total energy consumption has fallen dramatically, if only the domestic production is regarded. If the consumption including imported fossil fuels and the transportation thereof is included, the result is different (Berglund et al, 2011). However, in the light of the soon-approaching 'peak oil', it is necessary to further reduce or even completely eliminate the country's need for petroleum, and because of climate change concerns, the consumption of all fossil fuels must be reduced. Furthermore, from a 'strong sustainability' perspective, the

<sup>2</sup> Titi Tudorancea Bulletin, <http://www.titudorancea.com/z/energy.htm>

overarching objective should be to reduce total energy consumption in the long term, although this is an unlikely outcome due to rising population and income levels (Neumayer, 2003).

According to the Commission on Oil Independence, appointed by the Swedish Government in 2006 to develop a proposal on how to further diminish Sweden's dependence on petroleum, Sweden has excellent climate and soil conditions for producing considerable amounts of bioenergy for heating, transport and industrial purposes. The Commission proposed increasing cultivation of energy crops to produce biofuels. Some projections were developed and are presented in the table below.

Table 1: Acreage for biofuels, 2005 to 2050<sup>3</sup>

| Acreages for biofuel                                      | 2005<br>ha | TWh | 2020<br>ha | TWh | 2050<br>ha | TWh |
|-----------------------------------------------------------|------------|-----|------------|-----|------------|-----|
| Agricultural land in total                                | 3 215 600  |     | 3 215 600  |     | 3 215 600  |     |
| comprising agricultural land for energy crops             | 80 000     | 0.5 | 160 000    | 2   | 400 000    | 11  |
| fallow acreage                                            | 320 000    | 0.0 | 320 000    | 4   | 320 000    | 10  |
| waste products, straw, fertiliser, etc.                   |            | 0.5 |            | 4   |            | 11  |
| previous agricultural land                                | 400 000    | 0   | 400.00     | 2   | 400 000    | 12  |
| Forest land in total                                      | 23 000 000 |     | 23 000 000 |     | 23 000 000 |     |
| Production                                                |            | 94  |            | 94  |            | 94  |
| comprising increased productivity in existing forest land |            |     |            | 23  |            | 30  |
| intensive afforestation                                   | 0          | 0   | 200 000    | 2   | 1 150 000  | 27  |
| other biofuels, waste, peat, etc.                         |            | 13* |            | 23  |            | 33  |
| Total biofuel acreage ha/energy TWh                       | 26 615 600 | 108 | 26 615 600 | 154 | 26 615 600 | 228 |

\* including imports assessed to be 7-9 TWh in 2005

These projections show a fivefold increase in land area under energy crop production by 2050. Apart from production of biofuels from energy crops, bioenergy is also obtained by combustion agricultural and forestry residues. This is mainly done in district heating plants. Data on the quantities of residues used in this way are difficult to obtain, but the amount of ash generated from combustion of these residues at district heating plants is approximately 350000 tons per year. Of this amount, only 50000 tons are applied to forest land in order to return some carbon to the soil. The rest of the ash is disposed of at landfill sites (G. Thelin, personal communication). Peat is also used for bioenergy in Sweden, although the volume harvested has been decreasing in recent years, as peat is now regarded as a fossil fuel rather than a renewable energy source.

<sup>3</sup>Commission on Oil Independence, 2006: Making Sweden an Oil-free Society, Stockholm, Sweden

## 2.5 Agricultural productivity in Sweden

Agricultural productivity is the ratio of market value of agricultural outputs to agricultural inputs. The inputs and outputs are determined in monetary terms and then the ratio is calculated. Improving the efficiency of production raises the productivity.

Sweden has an area of 450 295 square kilometers. About 9% of this is water, leaving a land area of approximately 410 335 km<sup>2</sup>. Approximately 67% of the land is forested, and less than 10% is arable. Furthermore, there is a decreasing trend in the arable land area, as shown in the graph below. The decrease in arable land area is a result of erosion, compaction, loss of organic matter and contamination with pesticides, and in some areas, heavy metals (Stoate et al, 2001). Many common agricultural practices, especially ploughing and disc-tillage, accelerate the decomposition of soil organic matter and leave the soil susceptible to wind and water erosion (Bot & Benites, 2005). The removal of large quantities of organic material from the land also contributes to this problem. In 2009, the arable land area in Sweden amounted to 2,643 million hectares (SCB, 2010), which is equivalent to 26 430km<sup>2</sup>, only 6.4% of the total land area.

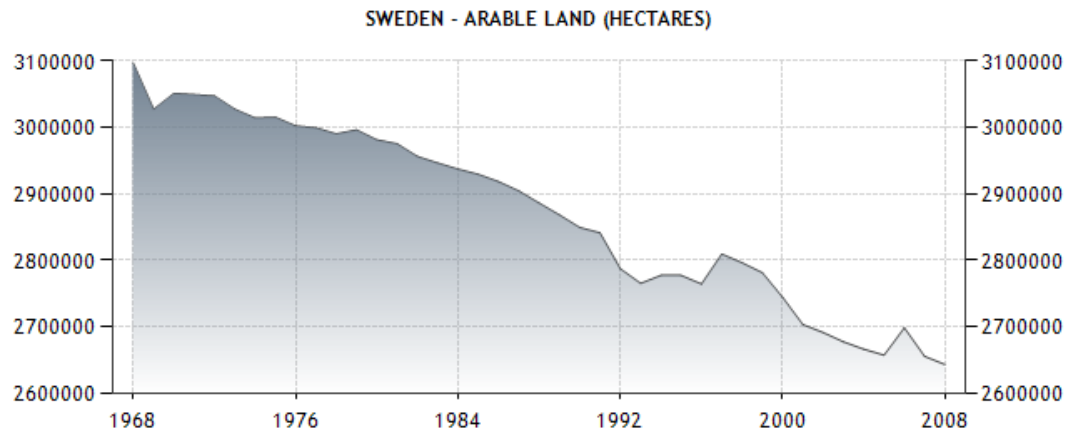


Figure 3: Declining arable land area in Sweden<sup>4</sup>

Soil organic matter content is a function of organic matter inputs (residues and roots) and litter decomposition. It is related to moisture, temperature and aeration, physical and chemical properties of the soils as well as mixing by soil macrofauna, leaching by water and humus stabilization (Bot & Benites, 2005). Land use and management practices also affect soil organic matter content. Soil organic matter content is particularly important in enabling the soil to retain moisture and nutrients, and providing a habitat for soil micro-organisms. Furthermore, the loss of soil organic matter has reduced the soil ecosystem's capacity for carbon sequestration (Stoate et al, 2001).

In addition to human activity, climate influences the soil organic matter content. The map below shows the projected loss in soil organic matter in European cropland in the period 1990 to 2080 under a projected climate change scenario.

<sup>4</sup> Arable land (hectares) in Sweden, <http://www.tradingeconomics.com/sweden/arable-land-hectares-wb-data.html>

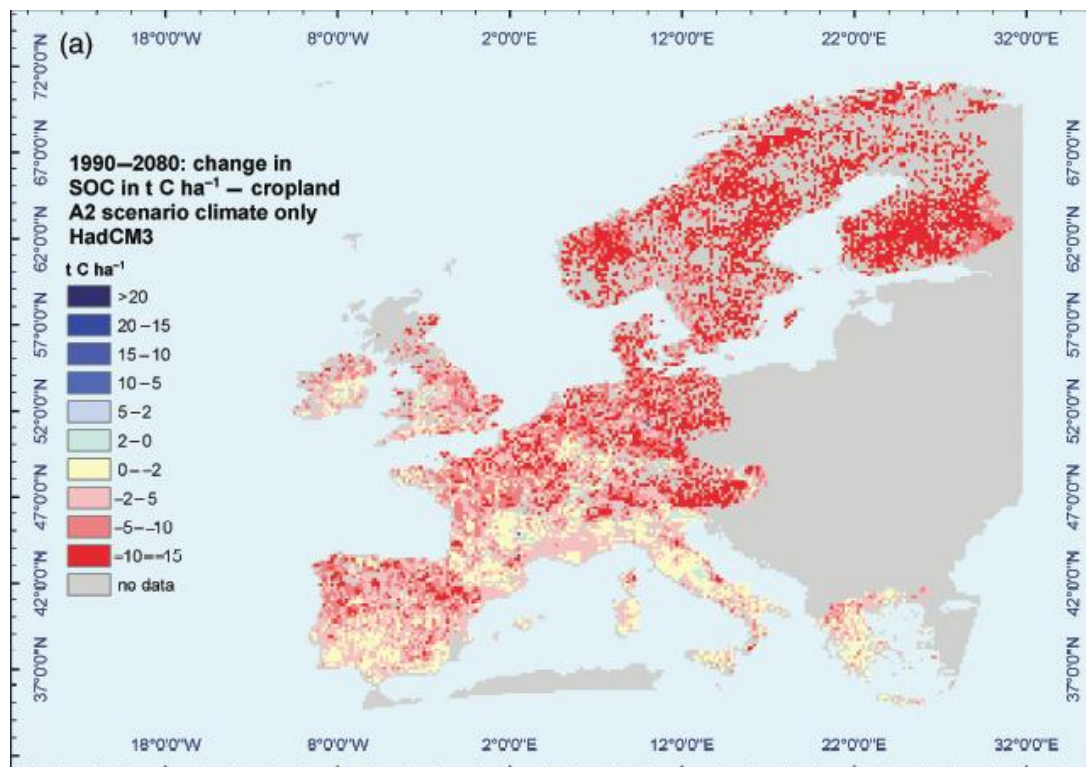


Figure 4: Loss of organic content in European cropland, 1990- 2080<sup>5</sup>

From this map it is evident that much of Sweden's cropland will lose 10% to 15% of its organic matter content during the stated period, due to climate effects only. Without a transformation of land management practices, the soils will become significantly degraded.

Although there is no universal threshold at which soil organic matter is considered to be low (Krull et al, 2004), results from various studies have shown that at organic matter contents of below 3%, most soils are prone to structural destabilisation and crop yields are reduced (Krull et al, 2004; Bertilsson, 2008; Grogan, 2010).

Studies from different parts of the world have shown that sandy and clayey soils that are low in organic matter content benefit the most from biochar application. It is envisaged that a biochar system, by enabling the soil to retain more water and nutrients and thereby reducing the amounts of inputs required, has the potential to increase agricultural productivity and carbon storage. Furthermore, application of biochar to degraded soils could fertilize them to a level that restores their potential as agricultural or grazing land.

The maps below illustrate the soil types in Sweden and the average content of organic matter in Sweden's farming regions.

<sup>5</sup> Smith, J., Smith, P., Wattenbach, M., Zaehle, S., Hiederer, R., Jones, R.J.A., Montanarella, L., Rounsevell, M.D.A., Reginster, I., Ewert, F., 2005: Projected changes in mineral soil carbon of European croplands and grasslands, 1990–2080, *Global Change Biology* 11, 2141–2152



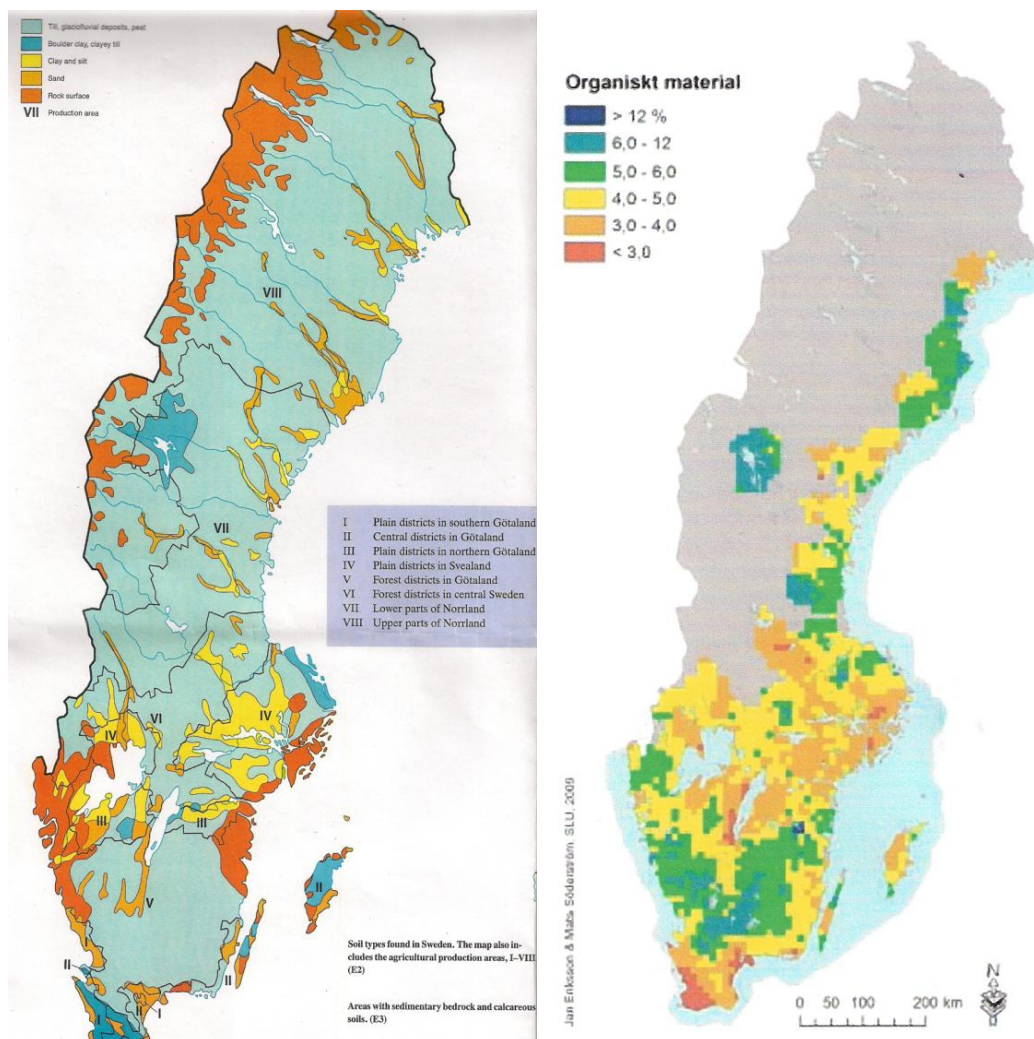


Figure 5: Soil types in Sweden; organic matter content in Sweden's agricultural regions<sup>6</sup>

The maps show that some areas with sandy and clayey soils have with low organic matter content, particularly in the southernmost part of the country. These areas should therefore be target areas for biochar application. Experiments in southern Sweden have shown that biochar can yield benefits in soils with a higher organic matter content of about 3.5 % (L. Hylander, personal communication, 2011-11-17). Bertilsson (2008) estimates that a soil with organic matter content exceeding 6% is carbon-rich. Thus, such soils are not under consideration for biochar application.

<sup>6</sup> Sveriges lantbruksuniversitet, 1992: *National Atlas of Sweden – Agriculture*, Uppsala, Sweden; Naturvårdsverket, 2010: *Tillståndet i svensk åkermark och gröda - Data från 2001-2007*, Rapport 6349, Naturvårdsverket, Stockholm, Sweden



## 2.6 Biochar systems

The most well-known example of biochar application to agricultural land is in the Amazon River catchment area, where, from 7000 to 500 years ago, farmers traditionally mixed biochar with compost and other residues and applied the material to the soil. Over time, carbon-rich, fertile soils were created this way, known as Terra Preta (Lehmann & Joseph, 2009).

Biochar systems are based on pyrolysis, the thermal decomposition of organic matter in an oxygen-depleted environment. Pyrolysis of biomass results in three co-products: biochar, bio-oil and syngas (Maraseni, 2010). Biochar is a form of charcoal with a highly stable carbon structure. Bio-oil is tarry oil that can be further distilled into various useful fractions. The gases yielded from pyrolysis may be used as fuel. The relative amounts and characteristics of these products depend on the pyrolysis processing conditions such as feedstock type, temperature, pressure and residence time (Roberts et al, 2010).

The biochar yielded from this process may either be used as a fuel, like coal or charcoal, or applied to the soil. Soil application of biochar returns organic matter to the soil and leads to improved aeration and retention of water, thus increasing crop yields. Another important benefit of biochar addition to soil is that it aids retention of nutrients. In the light of peak oil and peak phosphorus, it is increasingly important to avoid loss of nutrients from soil.

At the same time, biochar provides long-term carbon sequestration, as the carbon structure of biochar is highly stable. Studies have shown that sustainable global implementation of biochar systems could potentially offset a maximum of 12% of current anthropogenic CO<sub>2</sub>-C equivalent emissions (Woolf et al, 2010). Furthermore, it has been found that modest additions of biochar to soil reduce nitrous oxide N<sub>2</sub>O emissions by up to 80% and eliminate methane emissions, which are both more potent greenhouse gases than CO<sub>2</sub> (Graber, 2009).

Numerous studies have been conducted to determine which types of soil benefit from biochar application. The soil carbon level of the area where biochar is to be applied is serious concern, as much remains unknown about how charcoal influences the dynamics of native soil organic carbon and its loss as CO<sub>2</sub> (Wardle et al, 2008). For instance, a 10-year study where charcoal was prepared, mixed into the soil and left undisturbed under three contrasting forest stands in northern Sweden, found a substantial increase in soil bacteria and fungi. As a result, there was mineralisation (decomposition) of native soil organic matter with accelerated emissions of CO<sub>2</sub> (Wardle et al, 2008). This revealed that biochar application in carbon-rich soils could partially offset the GHG benefits; therefore, to maximise the overall benefits of biochar, it should be applied to carbon-poor soils (Maraseni, 2010).

In general, biochar addition increases the water holding capacity and plant-available moisture in sandy soils; in loamy soils, no changes are observed; and in clayey soil, the available soil moisture decreases with increasing biochar addition, probably through the hydrophobicity of biochar. Therefore, biochar soil water benefits are maximised in sandy soils (Maraseni, 2010).

If the hydrophobic character of biochar is more pronounced in clayey soils, it could be beneficial in areas with water logged clayey soils (Maraseni, 2010). The improved porosity of clay soils caused by biochar may help to improve soil drainage.

Biochar tends to increase pH value and works like lime. Thus, biochar should be applied to acidic rather than alkaline soils (Maraseni, 2010)

There are several biochar application methods available such as deep banding, seeding application, top dressing, aerial delivery and special application to ailing vegetation at the root (Blackwell et al, 2009). The application of biochar with seeds or fertilisers may be the best solution, as it does not require extra machinery (Maraseni, 2010). The effectiveness of application of composts, animal manures or mineral fertilisers is known to vary significantly depending on whether they are incorporated into the soil or applied to the surface, and similar responses can be expected to the method of biochar application (Blackwell et al, 2009).

The bio-oil produced during pyrolysis may be used for low-grade heating purposes or as an input in the chemicals industry, for production of biodiesel, for instance. The gases and heat generated from the pyrolysis process may be used for electricity generation (Hylander & Kihlberg, 2011).

Biochar systems provide an additional benefit of biomass waste management. Residues from agriculture and forestry are cleared and used as inputs into the pyrolysis process. The resulting biochar is of reduced volume and mass and much easier to store, transport and apply to the soil.

Thus, biochar systems may be optimised to achieve any of the following four potential benefits:

- Long-term carbon sequestration and reduced greenhouse gas emissions from soil
- Soil conditioning – returning organic matter, improving aeration, retaining nutrients, increasing water-holding capacity
- Renewable energy generation
- Biomass waste management.

Below is an illustration of a sustainable biochar concept.

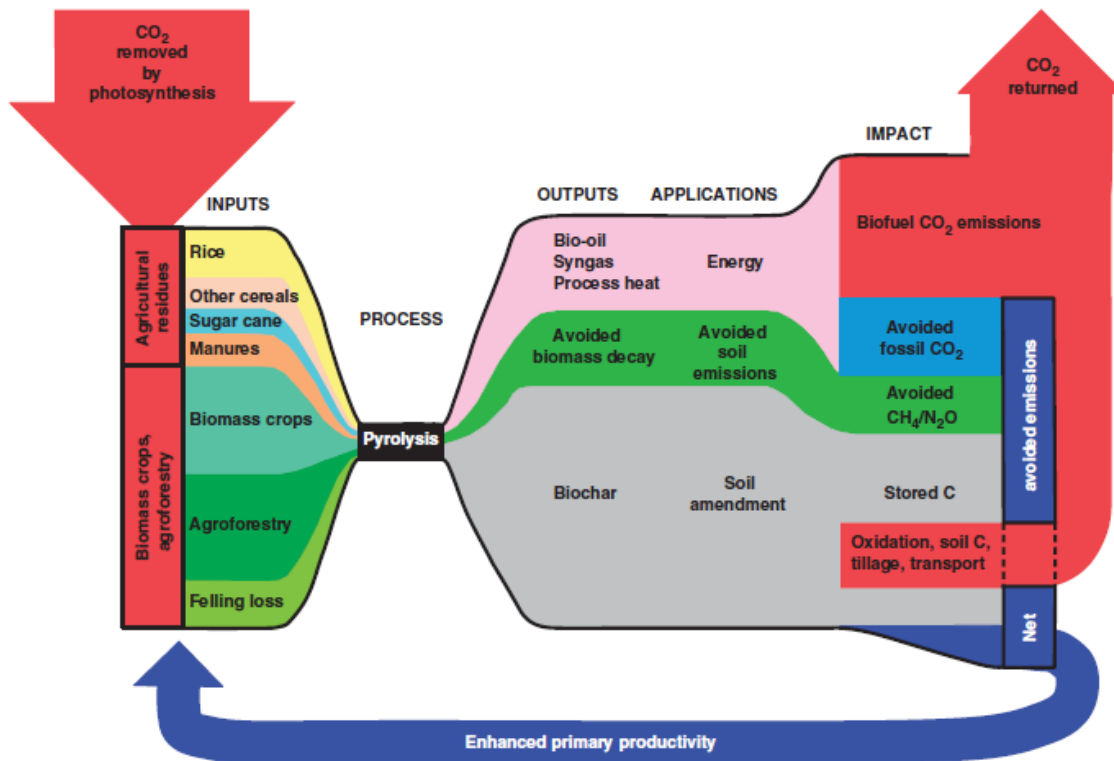


Figure 6: A sustainable biochar concept<sup>7</sup>

According to the diagram, pyrolysis of agricultural and forestry residues yields biochar, as well as energy and by-products, with the added benefit of reducing greenhouse gas emissions from biomass decay in the field. The storage of carbon by applying biochar to soil reduces the quantity of carbon dioxide returned to the atmosphere. Using the energy produced and the by-products reduces the requirements for fossil fuels.

<sup>7</sup> Woolf, D., Amonette, J.E., Alayne Street-Perott, F., Lehmann, J., Joseph, S., 2010: *Sustainable biochar to mitigate global climate change*, <http://www.nature.com/ncomms/journal/v1/n5/full/ncomms1053.html>

### 3. Results

This section presents the map work, experiment and calculations that were performed for the purposes of this study.

#### 3.1 Potential areas for increased agricultural productivity with biochar application

In order to identify the areas of arable land in Sweden that could benefit from application of biochar, a map was created by overlaying a map of soil types in Sweden with a map of organic matter content of arable soils.

The map below shows areas in Sweden that are critical for addition of biochar, that is, areas with sandy soils and less than 2% organic matter content.

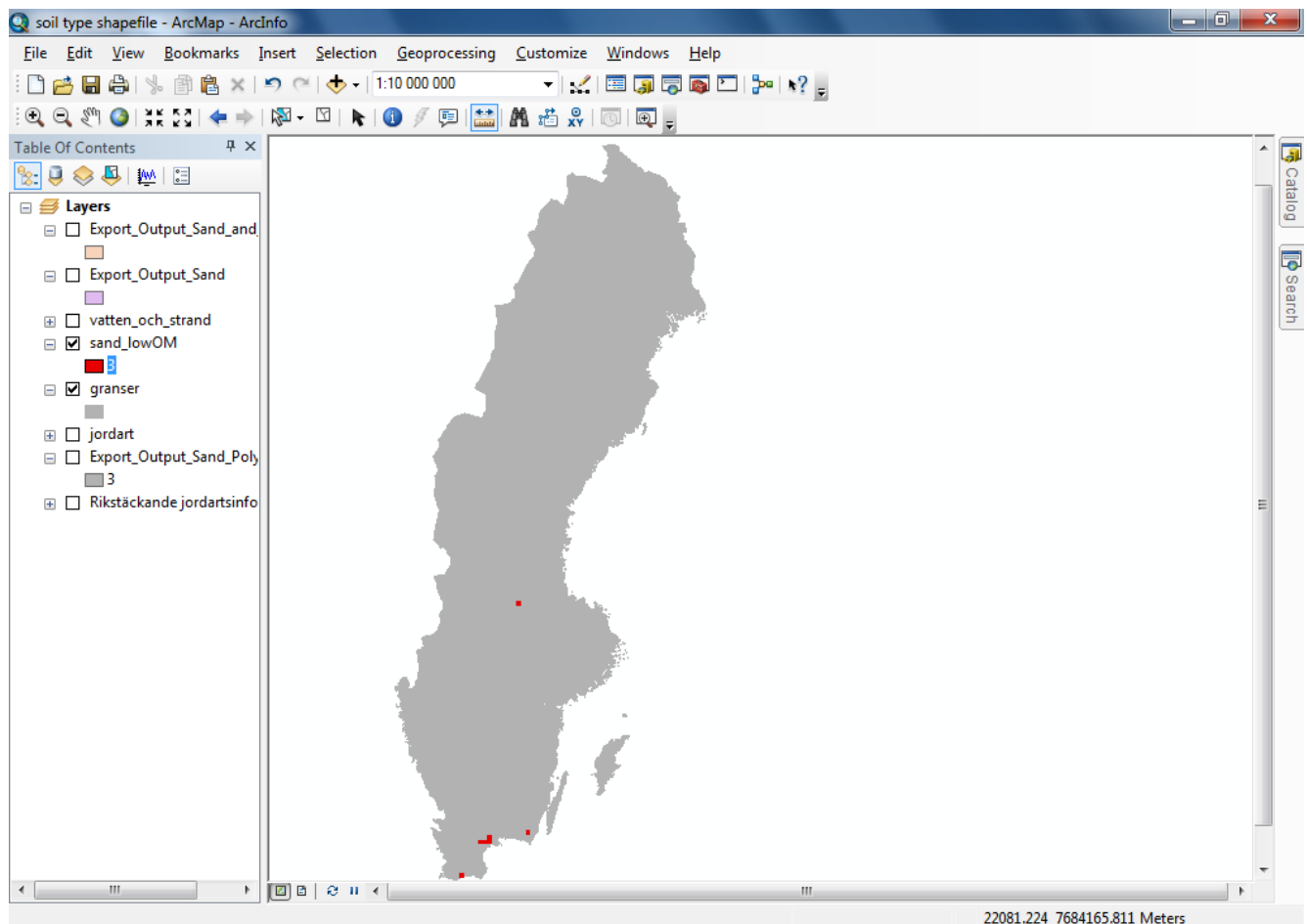


Figure 7: Critical areas for biochar application<sup>8</sup>

The area represents 700 km<sup>2</sup>

Total area of arable land in Sweden = 26 430km<sup>2</sup>

<sup>8</sup> Map developed with support from Andreas Bryhn, Uppsala University

$$\frac{700}{26430} = 0.026485$$

Thus, approximately **2.65%** of Sweden's arable land is critically in need of biochar application.

The map below shows land areas that could benefit agronomically from biochar addition, that is, areas with sand or clay soil and organic matter content of between 2% and 6%.

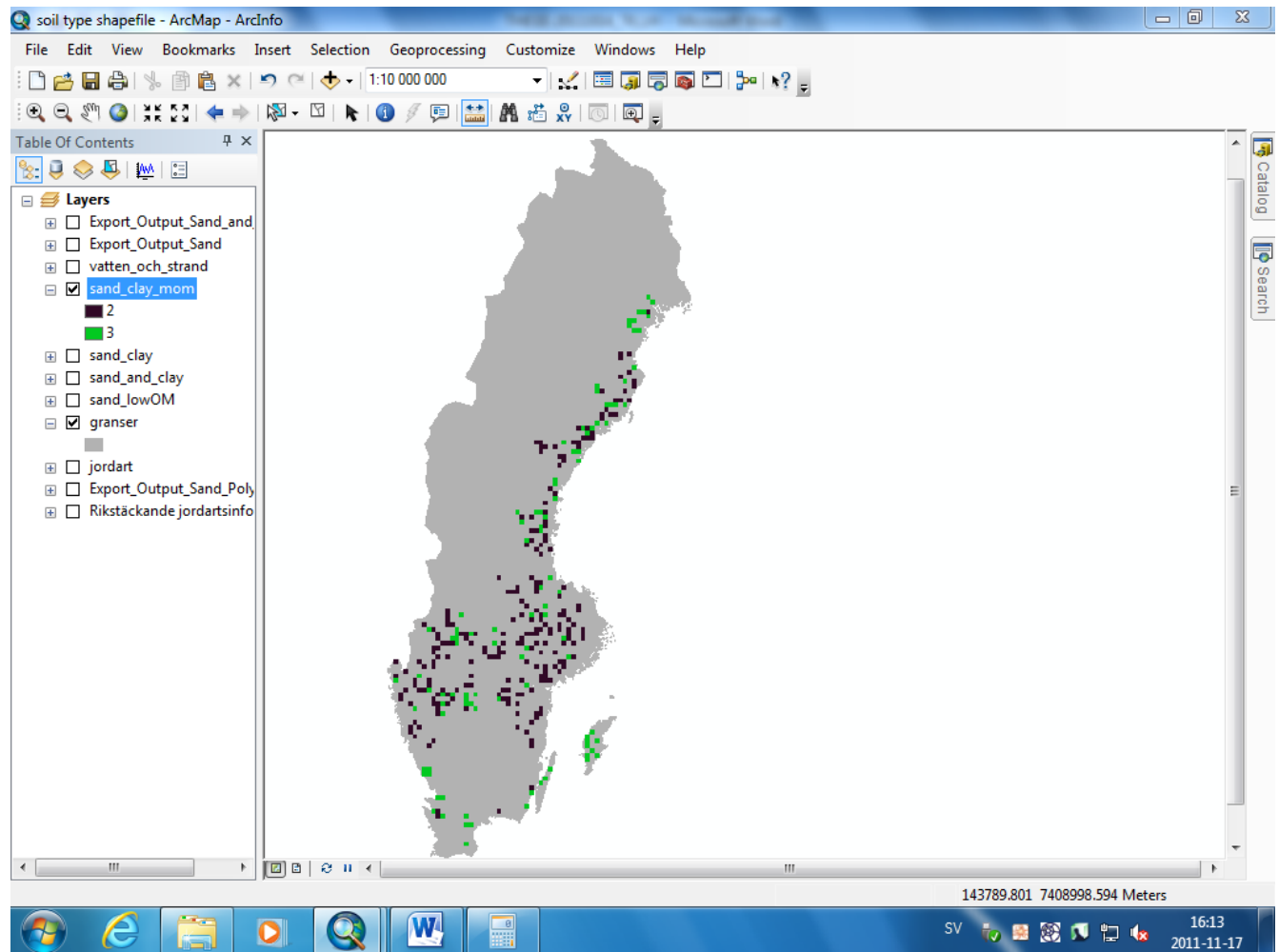


Figure 8: Potential areas for agronomic benefit from biochar application

The area represents 32 100 km<sup>2</sup>

Total area of arable land in Sweden = 26 430km<sup>2</sup>

$$\frac{32100}{26430} = 1.2145$$

This converts to 121.45% of the arable land area. This represents an area greater than the current arable land area. Thus, there is a possibility that with biochar application, some degraded land could be restored to agricultural use.

## 3.2 Pyrolysis of agricultural residues

Pyrolysis of biomass yields three co-products – biochar, bio-oil and syngas, the proportions of these depending on the type of feedstock, the pyrolysis temperature and the retention time. The pyrolysis process also yields heat energy that could be used for applications such as district heating. An experiment was performed on an Adam-retort, in order to determine the yield of biochar and heat energy from the process.

The Adam-retort works in two stages. In the first stage the biomass in the retort chamber is dried by hot flue gases and the carbonization is initiated. Hot flue gases are produced with waste wood burned in an external fire chamber.

As soon as the moisture in the biomass has evaporated, the first inflammable organic gases appear. These gases are then rerouted into the fire chamber, reducing pollution. This additional energy is used to heat up the retort chamber and to further accelerate carbonization.

**Date of experiment:** 02 September 2011

**Process:** A standard bale of barley straw weighing 150kg with 15% moisture content was loaded into the retort chamber. The fire chamber was loaded with 60kg of firewood and ignited at 09:18. The wood was burned to raise the temperature of the metal plate beneath the straw.



Figure 9: Adam-retort and fire chamber

**Observation:** Initially the smoke from the retort chamber was white, consisting of steam from the straw and smoke from the wood.

When the moisture content of the straw had been evaporated and the material began to pyrolyse, the flue gas became yellow in colour, indicating the presence of organics.

At 13:15 the temperature had risen to the target of 330°C. The steam vent from the retort chamber was closed and the smoke pipes from the fire chamber to the retort chamber were plugged, to force the flue gases to recirculate through the furnace.

After the steam vent was closed, the temperature began to fall.



At 16:00 the fire was extinguished and the insulation removed from the top of the retort. The retort and its contents were left to cool overnight.



Figure 10: Adam-retort with steam vent closed; partially pyrolysed straw

**Result:** The following day, the retort was opened to examine the contents. The resulting material was a mixture of ash and only partially pyrolysed straw. The yield of biochar was visibly less than the expected 30%.

**Interpretation:** The temperature fell after the steam vent was removed because there was insufficient pressure to force the flue gases through the fire chamber, as the biomass was not dense enough to create a build-up of pressure.

Thus, there must have been some oxygen remaining in the pyrolysis compartment, hence the combustion of a large proportion of the material

Due to the low density of the straw the amount of biomass in the retort was too small to yield a sufficient flow of pyrolysis gases. The low density also hindered efficient heat transfer to the biomass. Furthermore it seemed that straw requires a higher temperature than wood to start the pyrolysis process.

**Conclusion:** The feedstock should be denser if the material is to be properly pyrolysed. This could be achieved by pelletising the straw before pyrolysing it, so that it is more compact and thus allows for less air space than straw in its natural form. For either batch or continuous pyrolysis of straw to be successful, the straw must be compact, either in the form of pellets or briquettes.

### 3.3 Comparison of scenarios for agricultural residue management

Agricultural residues can be used in various ways, depending on local needs. One important function of agricultural residue is maintaining organic matter content in soil. The organic matter level of any given soil is largely controlled by the quantity and nature of organic matter inputs, of which crop residues represent a significant part (Anders & Recous, 1997). An important benefit of charring agricultural residues is that the char decomposes at a slower rate than the residues

would in their untreated state. Rapid decomposition of organic matter in the soil is undesirable because it allows the nutrients to be quickly leached out. Thus, as a form of crop residue management, it would be beneficial to compute what fraction of the available residue should be ploughed into the soil in its natural state, and what portion should be charred in order to sustain organic matter and nutrient content in the soil.

The dynamics of crop residue decomposition in soils are complex and are controlled by many factors including: nutrient and water availability, temperature, physical and chemical nature of the residue, soil type and soil-residue contact (Bot & Benites, 2005). The same factors may influence the decomposition of biochar in soil, but to a lesser extent because biochar is more stable.

The calculations below show the rates of decomposition of charred and untreated agricultural residues.

### **Demonstration of the accumulation of carbon in soils due to biochar application<sup>9</sup>**

From Bertilsson (2008): Assume humus content: 2 %, which is equivalent to a carbon content of 1.2 %.

Amount of carbon per hectare in the form of humus: 36 tons.

Degradation of humus: 1.5 % per year.

Total amount of biomass per year minus grain (i.e. straw, stubble, roots and root zone depositions): 7.5 tons per hectare per year.

Quantity of biomass in the straw and chaff: 4.5 tons.

Content of carbon in the biomass: 44% of dry mass (Pathak et al, 1986)

Quantity of straw plus chaff in dry mass that can be pyrolysed or incinerated: 4.5 tons, moisture content 20 %. Completely dry: 80% of 4.5 tons: 3.6 tons

Amount of ash in % of normal damp straw: 5 %.

Amount of carbon in the biomass from all biomass except grain:  $7.5 \times 0.8 \times 0.95 \times 0.44 = 2.5$  tons

Amount of carbon in stubble, roots and root zoon deposition:  $(7,5 - 4,5) \times 0,8 \times 0,95 \times 0,44 = 1,0$  ton.

Amount of carbon in the biomass from straw plus chaff:  $3.6 \times 0.95 \times 0.44 = 1.5$  tons.

Straw in soil: 84 % decomposition in 8 years, 91 % in 20 years, between years 8-20 year the half-life is 15 years (Sørensen, 1987). From the graph (Fig. 1.) in this paper:

During the first year the amount of carbon reduces from 100 % to 30 %. From year 1 to year 10 the amount of carbon is reduces almost linearly from 30 % to 14 %.  $Y = m \times (0.3 \text{ to } 0.0178 \times A)$  where A is the year from year 2 (= 1-9), and m is the mass of carbon in biomass. After 10 years there is an exponentially decay with a half-life of 15 years.

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<sup>9</sup> Mathematical expressions developed by Tor Kihlberg, Uppsala University



If  $X^{15} = 0.5$  then  $X = 0.9548$

$\ln 0.9548 = -0.046$

Thus, there is a 4.6% reduction per year. This is considerably higher than the 1-2% mineralization Bertilsson (2008) states.

Yield of biochar from dry straw plus chaff: 32% (Mahinpey et al, 2009).

Carbon content of biochar from straw: 70% (Mahinpey et al, 2009).

Amount of carbon in biochar from straw plus chaff:  $3.6 \times 0.32 \times 0.7 = 0.81$  tons per hectare

The half-life of biochar from straw pyrolysed at 525°C: 930 years.

If  $X^{930} = 0.5$  then  $X = 0.999255$ . This corresponds to 99.9255% remaining amount each year.

**Scenario 1: All biomass except the grains is returned to the soil.**

Year 0:  $36 + 2,5$  ton carbon.

Year 1:  $36 \times 0,985 + 2,5 + 2,5 \times 0,3$ .

Year 2:  $36 \times 0,985^2 + 2,5 + 2,5 \times 0,3 + 2,5 \times (0,3 - 0,0178 \times 1,0)$

Year 3:  $36 \times 0,985^3 + 2,5 + 2,5 \times 0,3 + 2,5 \times (0,3 - 0,0178 \times 1,0) + 2,5 \times (0,3 - 0,0178 \times 2)$ .

Year 4:  $36 \times 0,985^4 + 2,5 + 2,5 \times 0,3 + 2,5 \times (0,3 - 0,0178 \times 1,0) + 2,5 \times (0,3 - 0,0178 \times 2) + 2,5 \times (0,3 - 0,0178 \times 3)$ .

Expressed as a sum:

$36 \times 0,985^p + 2,5 + \sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1))$ , where p is the number of years from start.

Between year 10 and 20:

$36 \times 0,985^p + 2,5 + \sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,954^p$

Between year 20 and 30:

$36 \times 0,985^p + 2,5 + \sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,955^p + (\sum_{n=1}^{n=10} 2,5 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,954^{p-10}$

**Scenario 2: All straw plus chaff is removed and incinerated to ash in a heating plant. The rest of the biomass except grains is retained in the soil.**

Year 0: 36 + 1,0 ton carbon.

Year 1:  $36 \times 0,985 + 1,0 + 1,0 \times 0,3$ .

Year 2:  $36 \times 0,985^2 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0)$

Year 3:  $36 \times 0,985^3 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0) + 1,0 \times (0,3 - 0,0178 \times 2)$ .

Year 4:  $36 \times 0,985^4 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0) + 1,0 \times (0,3 - 0,0178 \times 2) + 1,0 \times (0,3 - 0,0178 \times 3)$ .

Expressed as a sum:

$26 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))$ , where p is the number of years from start.

Between year 10 and 20:

$36 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,955^p$

Between year 20 and 30:

$36 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,955^p + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,955^{p-10}$

**Scenario 3: All straw plus chaff is pyrolysed and the formed biochar is returned to the soil. The rest of the biomass except grains is retained in the soil.**

Year 0: 36 + 1,0 ton + 0,81 ton carbon.

Year 1:  $36 \times 0,985 + 1,0 + 1,0 \times 0,3 + 0,81 \times 2 \times 0,999255^2$ .

Year 2:  $36 \times 0,985^2 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0) + 0,81 \times 3 \times 0,999255^3$

Year 3:  $36 \times 0,985^3 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0) + 1,0 \times (0,3 - 0,0178 \times 2) + 0,81 \times 4 \times 0,999255^4$ .

Year 4:  $36 \times 0,985^4 + 1,0 + 1,0 \times 0,3 + 1,0 \times (0,3 - 0,0178 \times 1,0) + 1,0 \times (0,3 - 0,0178 \times 2) + 1,0 \times (0,3 - 0,0178 \times 3) + 0,81 \times 5 \times 0,999255^5$ .

Expressed as a sum:

$36 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1)) + 0,81 \times (p+1) \times 0,999255^{p+1}$ , where p is the number of years from start.

Between year 10 and 20:

$$36 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,954^p + 0,81 \times (p+1) \times 0,999255^{p+1}$$

Between year 20 and 30:

$$36 \times 0,985^p + 1,0 + \sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1)) + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,954^p + (\sum_{n=1}^{n=10} 1,0 \cdot (0,3 - 0,0178 \cdot (n - 1))) \times 0,954^{p-10} \times 0,81 \times (p+1) \times 0,999255^{p+1}$$

The rationale for developing such mathematical expressions is to facilitate estimation of the cumulative carbon storage benefit accrued by annual application of biochar to soil. The expressions also facilitate comparison of three options: leaving all biomass on the soil to decompose naturally, removing all above-ground biomass and incinerating it for energy production, or pyrolysing it and returning the biochar to the soil.

A fourth option, balancing competing needs for sustained soil quality, bioenergy and carbon storage, would be to pyrolyse only a fraction of the above-ground biomass and return the biochar to the soil. Computation of the fraction of organic matter that should be converted to biochar is a subject for further research.

## 4. Discussion

### 4.1 Review of the findings

Environmental sustainability in Sweden is under threat from rising greenhouse gas emissions from transportation and industry. There has been a rapid increase in recent years in the use of biomass for electricity generation and district heating. However, from the information presented in the previous chapters, it is clear that Sweden's current bioenergy production system may not be sustainable in the long run, for the following reasons:

- Harvesting agricultural and forestry residues for energy production may leave insufficient organic matter in the soil, depending on the relative size of the plants' root systems; thus, over time the soil quality is depleted, reducing future yields;
- When ash is spread over the land to return organic matter to the soil, it causes a sudden nutrient overload but is then quickly washed or blown away, leaving no long-term benefit to the soil and instead ending up in water bodies where it contributes to eutrophication. This is particularly true of ash from agricultural residues, as some of the mineral nutrients from the fertilizers applied to the crops are retained in the ash;
- Increasing the acreage of energy crops has negative effects on local ecosystems, as large areas of monoculture create 'ecological deserts' – areas of very low biodiversity.

Thus, there is need for a more sustainable means of bioenergy production that does not deplete but rather enhances the ecosystems from which the crops or residues are sourced.

There is also need to investigate mechanisms of capturing and storing carbon, as well as preventing emissions of greenhouse gases. Applying biochar to soil is one such mechanism.

### 4.2 Proposed solution

Biochar, like any other proposed means of mitigating climate change, has met with doubts and skepticism. There are worries that if biochar production is pursued on a large scale, there might be unjust appropriation of land for cultivation of feedstock, with resulting deforestation and ecosystem destruction. Some skeptics argue that even if biochar helps plants access nutrients, plants need those in the first place and if all available organic residues are charred, synthetic fertilizers become the only option (H.O.M.E., 2011). Studies have been conducted to determine how long the carbon stored in the biochar will remain in the soil, but this may be highly dependent on the parameters of the pyrolysis process, and local climatic conditions (Lehmann & Joseph, 2009).

The following system is proposed:

- I. Biomass for bioenergy production should consist mainly of agricultural and forestry residues rather than purposely cultivated energy crops. Land use change to grow more energy crops should be avoided, as this is not environmentally sustainable. Cultivation of energy crops should be limited to meager soils that cannot presently be used for agriculture or forestry.

- II. A fraction of the agricultural and forestry residues collected for combustion should be pyrolysed instead. This could be achieved by installing pyrolysis units at district heating plants. The fraction of the residues that is pyrolysed should depend on the local needs for heat energy and biochar respectively.
- III. Some of the biochar obtained from the pyrolysis should be returned to local farmers, who should then apply it to depleted soils. The advantages of biochar over ash are that its larger particle size makes it less susceptible to being washed or blown away; its more compact structure prevents sudden nutrient overload to the soil; and its stable carbon structure sequesters carbon.

These three steps create a cyclic process that sequesters carbon and provides bioenergy while enhancing soil quality. Additionally, the process helps to sustain a diversified landscape for biological diversity, resilience and recreational value.

The energy yield from pyrolysing biomass is lower than that of combusting it. Nonetheless, this proposed solution is more sustainable than the current situation, in spite of reduced energy output, because it yields additional benefits such as carbon storage, reduced nutrient leakage, and recovery of meager soils. Thus, although a biochar system might cause a loss of revenue to the energy companies operating the district heating plants, this could be compensated for by establishing a tax rebate system, in which the energy company obtains tax reductions based on the quantity of biochar produced. District heating companies are professional organisations that analyse the production costs of their plants carefully and compare them to alternatives. They could therefore be expected to react quickly to changes in the taxation system. The fact that many of the companies are, or have until recently been, publicly owned has probably increased their sensitivity to local political environmental goals, which has led to investments also in such biomass technologies which, from a strictly business economic point, appears questionable (Johansson et al, 2002).

The government could also consider providing an incentive to farmers to apply biochar to their land, at least in the initial implementation stage of the biochar system. As industries in Sweden pay a carbon tax to the state for the quantity of carbon dioxide they emit, it should follow that farmers should receive an incentive for sequestering carbon by applying biochar to their land.

The costs to the government in providing these incentives and rebates would be recovered in the long term through increased agricultural productivity and lower expenditure on imported commercial fertilizer.

The biochar system proposed in this report does not envisage land use change for cultivation of feedstock, nor does it support maximization of bioenergy production at all costs. The objective is to make the current bioenergy production system in Sweden more sustainable by returning some of the carbon and nutrients from the biomass to the soil. It must be emphasized that not all agricultural and forestry residues should be turned to biochar; in fact, not all residues should be collected for combustion, either. Micro-organisms in the soil need some biomass in plant form as food, so it would be unsustainable to combust or pyrolyse all residues.

Furthermore, when a tree has been cut down for the purpose of providing wood products or paper, only about half of the biomass ends up as the desired product (Kåberger, 2005). The other

half is available as co-products for energy purposes. Later on, once the wood has served its purpose as building materials or the fibers have been recycled as paper a few times, most of the energy content may still be recovered. Thus, in a country such as Sweden with abundant forest resources and a large timber industry, it may not be necessary to grow trees or crops specifically for the production of biochar.

In the short-term perspective there are certainly more proven methods for climate mitigation, for example: better insulation of buildings, more efficient transportation and increased use of biogas as a vehicle fuel. These measures would reduce the per capita demand for energy in general and for fossil fuels in particular. But in the long run, population growth and rising income levels would continue to raise the global energy demand, thereby increasing greenhouse gas emissions. When the simpler, proven measures have been implemented, biochar could be considered as an additional option for climate mitigation both at national level and by individual farms and companies.

## 5. Conclusion

Ensuring environmental sustainability will require changes to several systems for production of goods and services. The focal points in the case of biochar are changes to energy production and agriculture.

As pyrolysis of biomass yields liquid and gaseous products which can be used as fuels, there is good potential for substitution of fossil fuels with biomass pyrolysis products, for heating applications. Biochar may also be used as a fuel. However, to ensure the sustainability of the system, it is recommended that the biochar be returned to the land so as to maintain soil fertility.

It may be argued that such a system is not yet necessary in Sweden as the country's arable land is still highly fertile, but this commonly held belief is not entirely accurate. The 1992 edition of the National Atlas of Sweden contains a soil fertility map that shows that even in the highly-productive South of Sweden, soil fertility was already becoming problematic almost 20 years ago (SLU, 1992a). It is likely that there has been further depletion of soils since then due to intense agricultural activity.

Revisiting the research questions:

1. *How can the implementation of biochar systems contribute to environmental sustainability in Sweden?*

Relating this question to Sweden's environmental quality objectives, it is clear from the results that biochar could make a significant contribution to achieving the objectives of reduced climate impact and promoting a varied agricultural landscape. Biochar applied to soil would store carbon and rejuvenate degraded soils.

2. *What are the most practical means of implementing biochar systems in Sweden?*

A small-scale option would be individual production and application of biochar on farms. But the economies of scale would likely favour centralized production at local district heating plants.

3. *Which areas in Sweden would benefit the most from implementing biochar systems?*

The maps produced in this project show the areas that could benefit from biochar addition. These are mostly along the eastern coast and in the southern-central part of the country. The area that could benefit from biochar application exceeds the current arable land area, indicating that biochar application could restore some depleted soils. Some locations in the southernmost part of Sweden are in critical need of organic material input. About 2.65% of the country's arable land area is in this critical state.

Revisiting the hypotheses:

*Hypothesis 1: Biochar has the potential to contribute to climate change mitigation in Sweden.*

At present, there is insufficient research to prove the viability of the biochar concept in Sweden. However, it is scientifically proven that pyrolysing organic material makes its carbon content more stable, slowing down its mineralization. Thus, this is a subject worthy of further research, but not yet of broad-scale implementation. Its value as a climate change mitigation tool is likely to rise in the future when other simpler, more obvious measures have been exhausted.

*Hypothesis 2: Biochar systems have the potential to increase agricultural productivity in Sweden, by enabling carbon-depleted soils to retain more water and nutrients, thereby reducing the amounts of agricultural inputs required.*

Recent field trials are showing positive results, although they could not be referenced in this thesis as they were yet to be published. More field trials are needed, in different soil types and in different parts of the country. This thesis has provided maps indicating where the most benefit would likely be achieved.

Thus, biochar systems, that enhance rather than deplete the land, should be an essential long-term component of Sweden's progress towards environmental sustainability. Biochar systems present part of the solution to the challenge of ensuring environmental sustainability.



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Appendix I  
Transcript of Telephone Interview with Gunnar Thelin,  
CEO of EkoBalans Fenix AB  
05 April 2011

**Introduction**

EkoBalans develops residue-based fertilizers and fertilization systems, provides solutions for the treatment of residues such as biogas digestate, sewage sludge and biomass ash, and provides contractor and consultant services in the forestry sector. EkoBalans processes digestate, sludge and ash to high quality, nutrient cycle-based fertilizers. The company's activities include forest fertilization and ash recycling for forestry companies and individual owners. EkoBalans also carries out training and work on a consultancy basis with surveys of soil and forest conditions, soil conservation measures, and permitting issues in the environmental sector. The company is located in Lund and works closely with the Lund University Faculty of Engineering.

Gunnar Thelin is the Chief Executive Officer of EkoBalans Fenix AB. He holds a PhD in Plant Ecology and was previously an Associate Professor at Lund University.

**Interview**

*1. Do you foresee an increase in cultivation of bioenergy crops in Sweden? Is this something Sweden needs, or could there be better local sources of renewable energy?*

Sweden has half a million hectares of arable land available for bioenergy cropping, as a result of subsidies to farmers to regulate food production in the 1990s. Farmers were paid not to farm portions of their land in order to avoid overproduction of food in the EU, and most of this land has remained unfarmed as there has been no need for increased local food production. This abandoned land is therefore available for growing energy crops. Of preference in Sweden is Salix, low-input forest plants that can be harvested for several years without replanting, which are therefore highly profitable. This kind of short-rotation forestry requires high capital outlay but little time and labor input. Energy crops are competing favorably on the international market, and local farmers therefore realize the potential for profit from this. A limiting factor is the capital required at the outset; most farmers might not have the start-up capital required to start up a bioenergy forest.

As Sweden is already sufficient in electricity production (from hydro and nuclear) and its greatest energy needs are for heat energy and transportation fuel, bioenergy plays a very big role in Sweden and the demand for it is likely to increase. Sweden also exports bioenergy forestry products and the demand is growing, thus production is likely to increase.

At present, 99% of the biomass use for energy in Sweden is from forestry residues. Agricultural residues are used as fodder and to line stables in order to collect fecal matter from the livestock, which is then used as manure. Manure often has to be dewatered for transportation and sale, as virtually all commercial farms are specialized in either one particular type of livestock or a particular crop; thus manure is sold from livestock farms to cropping farms.

*2. How does the cycle of agricultural/forestry residue collection, transport, drying, combustion and ash disposal work in Sweden? Is there any application of unprocessed ash to farmland or forests?*

In Sweden, about 75% of forests are privately owned, with the remaining 25% belonging to the state or forestry companies. Tree cutting, residue harvesting and ash disposal are all usually done by different entrepreneurs. About 50% of all material from clear-cut forest is processed for bioenergy. Most of the ash is used to cover landfills, and a small proportion is used for forest fertilization. About 350 000 tons of non-contaminated ash that could be used as fertilizer are produced from the combustion of biomass per year, but only about 50 000 tons are used for forest fertilization. The area to which ash is returned is only about 5% of the area from which forest is harvested.

*3. In your view, would production of biochar at district heating plants, with subsequent supply to local farmers, be practical? What might be some likely constraints?*

District heating plants do not currently have facilities for pyrolysis of biomass, and would be unlikely to invest in them, because biochar production reduces the overall heat energy yield. What are currently underway in Sweden are gasification plants to produce DME and hydrogen for vehicle fuel. The residue from gasification is biochar, which could then be purchased by farmers. The gasification plants are likely to be built in proximity to district heating plants so that the waste heat from the gasification process can be passed on to the district heating plant.

*4. In your experiments with using biochar in your fertilizers, what other materials will the biochar be combined with?*

EkoBalans aims to produce fertilizers that are as similar as possible to existing chemical fertilizers so that farmers can apply them with their existing machines. The biochar-based fertilizer will basically be a nutrient-enriched biochar. At present, EkoBalans does forest fertilization by applying a two-step process – ash application followed by nitrogen fertilization, using ammonium nitrate. The company intends to replace the ammonium nitrate with recycled nitrogen products in the future.

*5. How does the demand for your products compare with that for chemical fertilizers? Are your products considered suitable for use in organic farming?*

Fertilizers produced from rest-products are currently in greater demand for forest fertilization than for agriculture, and the demand is highest in Northern Sweden. In agriculture, the farmer buys fertilizer and applies it to the farm; in forestry, on the other hand, the landowner normally hires a contractor to do fertilization, as it requires specialized equipment.

EkoBalans is currently developing fertilizers for use in agriculture, which are intended to be launched in the next one year. Price projections indicate that these products will be marketable at current commercial fertilizer prices.

There are no fertilizer products on the market yet that are approved for use in organic farming. Organic farmers practice crop rotation in order to balance nutrients in the soil, in particular using nitrogen-fixing plants such as legumes to maintain nitrogen content. The main problem affecting

organic farms is depletion of phosphorus content in the soil. Organic farms currently depend on phosphorus in the soil left over from when the farm was a conventional farm. But this phosphorus content depletes every year, and farmers are aware of the need to replenish it. Thus, there is likely to be demand for recycled fertilizer products from organic sources.

At the global scale, phosphorus reserves are diminishing rapidly, with 'peak phosphorus' likely to be reached in 20 to 30 years. Thus, nutrient recycling will become increasingly necessary in the future.



## Appendix II

Transcript of Telephone Interview with Peter Lustig,  
Business Coach at Lantbrukarnas Riksförbund - The Federation of Swedish Farmers  
11 May 2011

### Introduction

The Federation of Swedish Farmers – LRF – is an interest and business organization for the green industry with approximately 170 000 individual members. Together it represents some 90 000 enterprises, which makes LRF the largest organization for small enterprises in Sweden.

Almost all cooperatives within Swedish agriculture and forestry are also members. LRF, and its seven subsidiaries, promote development of the green industry and bring together farmers of agricultural and forest land, as well as entrepreneurs so that they can fulfill their vision of growth and profitability.

LRF seeks to create the appropriate conditions for sustainable and competitive companies and to develop a favorable base for social life and enterprise in rural areas.

Peter Lustig is an entrepreneur coach for the Mälardalen branch of LRF, which covers the Stockholm, Uppsala and Vasteras regions. In this role he guides green sector entrepreneurs in developing and diversifying their business. He specializes in advising on energy issues including bioenergy production.

### Interview

*1. Are Swedish farmers generally aware of the potential benefits of applying biochar to soil? Is there growing interest in this, and is it likely to become widespread in the future?*

There is still little known in Sweden among farmers both of potential and viability. There are trials now in progress that will partly alter that situation. Biochar and its potential are not yet widely understood. The farmers in Knivsta who are testing biochar on their farms have problematic soils that they think could benefit from improved soil structure. They are also concerned about climate change mitigation. Farmers need to be made aware of the multiple benefits of implementing biochar. The possibility of making biochar with straw must be developed, so that farmers do not have to source raw material from elsewhere.

*2. How do Swedish organic farmers maintain the fertility of their soils? Could biochar be a possible solution for them?*

Organic farmers maintain the fertility of their soils mainly by incorporating organic matter in the form of crop residues and farmyard manure. Organic farms often have a more complex system than conventional farms, and are likely to practice mixed cropping as well as animal husbandry on the same farm. Organic farms that do not have animals may procure manure from other farms. The viability of biochar as another option for organic farmers is still to be seen.

*3. How open are Swedish farmers to testing new ideas or concepts? Does the agriculture sector participate actively in research and development?*

Farmers in Sweden are quite open to experimenting with new ideas. Active participation in research activity differs from place to place, but on a general note I would say it is increasing. Swedish farmers are business-oriented; if a new idea brings the possibility of increasing yield or productivity, or improving soil quality, they will generally be open to try it.

*4. My project proposes a system in which some of the biomass supplied to district heating plants is pyrolysed instead of burned, and the biochar produced from the pyrolysis is sold to farmers to apply to the soil, to maintain soil fertility and sequester carbon. This would require that district heating plants install pyrolysis reactors and that farmers are made aware of the benefits of applying biochar to their land. The energy company's loss of income due to the lower yield of heat from pyrolysis would be made up for by the sale of biochar. The farmers' expenditure on biochar would be made up for by tax credits for carbon sequestration (my thesis proposes the introduction of a tax credit system for carbon sequestration, funded by the carbon tax paid by carbon-emitting industries). Do you think such a system could work in Sweden? What hindrances to its success do you foresee?*

My personal view is that it is not viable to link carbon emission and sequestration with a tax system, so that some can continue to emit CO<sub>2</sub> and just pay for the damage. The carbon offset system is artificial, in that it doesn't lead to real reductions in the amount of CO<sub>2</sub> emitted. It is not good to put monetary value on all things. Subsidies and other financial incentives often lead to the wrong outcomes. It doesn't help if some continue to emit and others sequester. What we need to do is to stop the use of fossil fuel and increase carbon sequestration at the same time.

Farmers are more likely to respond to a motivation for biochar that includes benefits to agriculture and the environment than merely monetary gain. They need to be made aware of its potential for soil improvement, prevention of nutrient loss, as well as climate change mitigation.

The system proposed in the project will involve transportation of straw from the farms to the district heating plants, and then transportation of biochar from the district heating plants back to the farms. This is not energy efficient and might not even be carbon-negative if the fuel used in transportation is factored in. It would also be costly, as it is not valuable to transport straw. What would be better would be for the farmers to be able to make their own biochar on the farm. Then they could also benefit from the use of the bio-oil by-product. This would be a simpler system that the farmer could manage by himself.

*5. To what extent are Swedish farmers taking an interest in growing bioenergy crops? How profitable is this at present compared with growing food crops?*

I would say not so much, because locally-produced biofuels are not yet competitive with petroleum. The profitability of growing bioenergy forest plantations such as Salix is on the rise. A fast-growing grass called rorflen is also being cultivated by some but is not yet a big contributor to the market. There are also limitations imposed by the harvest techniques currently available.

Biogas production from rest-products is currently one of the most popular means of generating bioenergy, and it is likely to increase, although at current petroleum-product prices it is not yet competitive. Projections show that if the retail price of gasoline rises from the current 14kr per liter to 16kr per liter, the profitability of biogas will be at par with that of gasoline. The cost of biogas production technology is falling while the demand for biogas is rising; thus, biogas is a fuel that is likely to become a major part of Sweden's energy supply in the future.

**Appendix III**  
Transcript of Interview with Erik Öqvist,  
Technician at Department of Earth Sciences, Uppsala University  
26 May 2011

**Introduction**

The Department of Earth Sciences, Air, Water and Landscape Sciences (LUVAL) at Uppsala University has undertaken a project to increase local knowledge about the potential benefits of biochar and to develop a 'charvester' – a mobile pyrolysis plant, similar to an agricultural machine, which can be fed with residues from both agriculture and forestry, as well as biomass grown specifically for the production of biochar.

Erik Öqvist deals with the technical development of pyrolysis units as well as biochar production from different organic materials.

**Interview**

*1. What are the technical difficulties associated with making biochar?*

As organic materials are bulky, transporting them is costly. Transportation of the raw material and the final product accounts for 50 – 70% of the cost of producing biochar, in addition to causing GHG emissions if fossil fuels are used for transportation. Mechanical homogenization of the inputs is also required – wood has to be chipped, and straw has to be cut or made into pellets to facilitate its use in a pyrolysis unit. Ensuring a sufficiently low moisture content of the input is essential, as the amount of energy required for pyrolysis is exponentially higher the wetter the material is. Here in Sweden this is a particularly challenging problem as the weather is wet for most of the year; thus, material intended for biochar production may have to be stored indoors for a year to be used in the following planting season.

The syngas that is produced as a co-product is difficult to compress and store, as it is an unstable mixture of carbon monoxide, carbon dioxide, hydrogen and volatiles. Thus, it must be used as it is produced, fed back into the pyrolysis burner to keep it running, or used as a fuel for some other process. Not recycling the gas partially negates the climate change mitigation effect of pyrolysis, as about half of the carbon in the original material is in the gaseous products. A process that does not capture and recycle the syngas is as harmful to the environment as traditional charcoal-burning. The Adam's retort, a simple, low-cost pyrolysis system, recycles about 75% of the gas produced, but this is still too low to render the system carbon-negative.

Bio-oil can be condensed from the gas. Its constituents and properties depend on the input material, retention time and temperature in the reactor, but it generally consists mostly of tars, terpenes and methanol. It can be distilled further or used for low-grade heating purposes.

*2. Could the average farmer build and operate his own reactor/retort large enough to make biochar from baled straw? Would this pose safety hazards? Costs and time involved?*

This would probably not be economically feasible in Sweden, as it would require a dedicated person to do it. Swedish farmers are accustomed to using highly mechanized systems and would therefore need a fully mechanized process that does not require physical labor. If a proper machine was available and there was some financial benefit from producing and using biochar, farmers would probably do it.

One safety hazard is the carbon monoxide produced by the process. In some countries there may be a requirement to install carbon monoxide sensors in order to protect people working with the equipment. Also, there is the possibility of the syngas igniting, or explosions occurring if the process instructions are not properly followed. Other hazards are posed by moving parts, electricity and high temperatures, as with several other mechanical processes.

*3. How far has the development of a mobile 'charvester' gone? Are farmers the target market?*

The development of a charvester that would satisfy the requirements of mechanized agriculture would require a team of several engineers and a large budget. The machine would have to be fully mechanized, reliable and easy to use. The biochar research group at LUVAL can develop a theoretical optimization but do not have the funds to develop a functional prototype.

*4. From your experiments, what is the average yield of biochar and bio-oil per ton of straw and per ton of wood chips?*

The yield of biochar from wood chips is about 30% by mass, and from straw pellets 25-28% by mass. If straw biomass is dried it could yield the same as from pellets. The yield of bio-oil depends on the input material. Wood with high tar content, such as pinewood, yields a lot of bio-oil.

*5. Are there any inputs required apart from the organic material?*

Some fuel is required to start the process, for example propane gas or firewood. Also, charcoal ignites spontaneously with atmospheric oxygen, and thus water must be added to prevent this.

*6. What is the maximum moisture content at which organic material can be pyrolysed?*

For wood, 13% moisture content is the maximum. The pyrolysis process is highly sensitive to the moisture content of the input material; if the moisture content is just 1-2% higher than this, the energy required to start the process is exponentially higher.

*7. Is it possible to measure the energy content of the biochar and the energy yield from the process?*

The energy content of biochar made from straw and from wood is different. Biochar made from straw has lower energy content because straw has higher inorganic ash content, with consists mostly of calcium. When straw biochar is applied to soil, the calcium raises the pH of the soil and strengthens the binding of soil particles, thus improving soil structure. However, this ash content reduces energy content by the same magnitude, e.g. if straw biochar has 10% ash content, it has 10% lower energy content. Although combustion yields more energy than pyrolysis, one advantage of pyrolysis of straw is that this is the most efficient way to yield energy from it, as

straw combustion corrodes machinery due to straw's potassium content. If straw is to be combusted, the furnace must be made of stainless steel, which costs five times as much as ordinary steel. Pyrolysis does not precipitate the potassium; hence some energy can be yielded from straw this way, while also producing biochar that is beneficial to agricultural soil.

**Appendix IV**  
Transcript of interview with Reino Abrahamsson and Björn Boström,  
Climate change policy specialists at Naturvårdsverket  
16 November 2011

**Introduction**

Naturvårdsverket, the Swedish Environmental Protection Agency, is the agency responsible for giving input on climate policy to the Ministry of the Environment. Reino Abrahamsson is the agricultural specialist in the climate change policy unit. Björn Boström is a forester and is one of Sweden's representatives in the international climate change negotiations.

**Interview**

*1. What are the dominant forms of climate mitigation activity in Sweden today?*

Within Sweden, climate mitigation policy focuses on taxation as a means for curbing energy demand and thereby reducing greenhouse gas emissions. The introduction of energy and carbon taxes has led to a decrease in local fossil fuel emissions. Biofuels are exempt from carbon tax; hence the rise in biofuel consumption. Internationally, Sweden's climate mitigation activities are guided by the international framework, the United Nations Framework Convention on Climate Change, and by European Union policies and instruments. Sweden participates in the Clean Development Mechanism (CDM) by sponsoring renewable energy projects in developing countries. Sweden also participates in emissions trading within the EU. Full information on the country's climate change mitigation activities is presented in Sweden's Fifth National Communication on Climate Change, available from the UNFCCC website.

Sweden is also lobbying internationally to decrease the limit on CO<sub>2</sub> atmospheric concentration from 450 ppm to 400ppm. At a concentration of 450ppm, there is only 50% probability that global temperature rise will not exceed 2°C. At 400ppm the probability is much higher.

*2. What is the progress on the environmental quality objective on reduced climate impact?*

Sweden aims to reduce carbon emissions by 40% by 2020 relative to 1990 emissions levels. Two-thirds of this reduction is to be achieved locally through taxation, and the remaining one-third is to be achieved abroad. A 15% reduction has been achieved so far. Carbon tax exemptions and credits are to be reviewed for agriculture, some classes of industry, and some types of vehicles. Sweden's latest climate policy bill contains a vision for zero net emissions by 2050.

*3. What are the future plans for climate mitigation, particularly relating to bioenergy?*

Energy policy in Sweden is the responsibility of the Swedish Energy Agency, Energimyndighet. This agency also manages the country's CDM activities. Sweden intends to continue to diversify its energy sources. Materials currently not used for large-scale energy production, such as straw, could come into use in the future, as in neighbouring

Denmark. The argument that straw corrodes district heating plant equipment is the same argument that was raised twenty years ago when forest residues were introduced as a substitute for fossil fuels. District heating plants had to be modified to suit the new material, and this could happen again if the use of straw becomes necessary. But at present, no incentive exists for using straw for bioenergy.

*4. What are the future plans for climate mitigation, particularly relating to agriculture?*

Agriculture and forestry are not yet major concerns for climate policy. This is because their greenhouse gas emissions and uptake are difficult to measure, and thus cannot be accounted for under the current international framework. In Sweden, it is estimated that the country's domestic land use emits 4-5 million tons of carbon per year, while the forests absorb 45 million tons. But neither of these figures can be accounted for, as land use emissions are excluded from carbon accounting except in cases of afforestation, reforestation or deforestation since 1990. Additionality of land use related carbon capture is difficult to prove. These issues are discussed in the working groups on land use, land use change and forestry (LULUCF) and reduction of emissions from deforestation and forest degradation in developing countries (REDD). A separate work programme on agriculture has been under discussion since 2009, but as yet there is no mandate to establish it.

*5. Is there currently any form of tax incentive/rebate for activities in Sweden that sequester carbon? Is this being considered for the future?*

So far there is no formal discussion on incentives for increasing uptake of CO<sub>2</sub>.

*6. What is Naturvårdsverket's position concerning the biochar concept? Is this being considered as an option for Sweden? Why, or why not?*

Naturvårdsverket has no formal position on biochar. The Swedish Board of Agriculture, Jordbruksverket, is engaged in research on means to improve carbon content in soils. Enhancement of soil carbon stock is important for agriculture. Jordbruksverket gives input to the Ministry for Rural Affairs for formulation of agricultural policy.

The main driver for biochar in Sweden would be interest from the farmers. However, there is little knowledge about biochar in Sweden at present. More research and knowledge dissemination would be required to spur farmers' interest in it.

From a climate perspective, a life cycle analysis would have to be conducted to determine biochar's total climate impact. The gains achieved by producing biochar and applying it to land may be negated by the emissions from transporting and processing the straw and biochar.

Internationally, in the current Kyoto Protocol text, LULUCF activities are only considered under the CDM, thus, only for implementation in non-Annex I countries. Biochar has been discussed in sub-groups under LULUCF and REDD, but mainly as a possible option for developing countries.